NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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FLIGHT INVESTIGATION OF A COMBINED GEARED UNBALANCING-TAB AND SERVOTAB CONTROL SYSTEM AS USED WITH AN ALL-MOVABLE HORIZONTAL TAIL

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SUMMARY

Results are presented of a flight investigation of a Curtiss XP-42 airplane equipped with an all-movable horizontal tail having a control system incorporating a combination of geared unbalancing tabs and servotabs. Previous investigations of the configuration had been made with a servotab control system for which the variations of elevator hinge moment with elevator deflection and with angle of attack were near zero. The stick-force variations with airspeed and acceleration were supplied by means of a bobweight. This system offered the possibility of having a constant control-force gradient regardless of altitude or center-of-gravity position. The servotab control system tested was found to be unsatisfactory, however, because of the light stick forces accompanying rapid elevator deflections.

In order to increase the stick forces for rapid deflections without affecting the forces in gradual maneuvers, the servotab linkage was modified by incorporating a viscous damper in one of the links so that the tabs deflected as geared unbalancing tabs for rapid stick motion. For slow motions, the damper allowed the tabs to operate as servotabs.

A flight investigation of this arrangement showed that the control characteristics were generally satisfactory in rapid maneuvers as well as in steady flight.

INTRODUCTION

An investigation was initiated to study a type of longitudinal-control system which would provide satisfactory control characteristics over a wide center-of-gravity range. In the development of such a control system, it is necessary to keep the value of C_{h_δ} (the variation of hinge-moment coefficient with control deflection) near zero and it is also desirable to keep C_{h_α} (the variation of hinge-moment coefficient with angle of attack) near zero and to supply the stick-force variation with speed and acceleration by means of a bobweight. This arrangement

would be expected to eliminate the variation in stick-force gradient with center-of-gravity position and altitude and yet provide adequate static longitudinal stability and force per g.

In order to obtain the desired hinge-moment characteristics of the control surface, an all-movable horizontal tail operated by servotabs was used. This tail was tested previously on the Curtiss XP-42 airplane and the results of these tests are reported in reference 1. The stability and control characteristics obtained in steady maneuvers were satisfactory, but the servotab control system gave too light stick forces for rapid elevator deflections. This condition resulted from the fact that the normal acceleration did not build up immediately when the elevator was deflected rapidly and therefore the bobweight did not have time to provide stick force for these rapid elevator deflections. It was suspected also that there might be some undesirable characteristics in addition to the servotab control system inherent in the all-movable tail. In order to learn whether the all-movable tail could be used as a satisfactory longitudinal control, the servotabs were changed to geared unbalancing tabs (reference 2). The deflection ratio between the geared unbalancing tabs and the all-movable horizontal tail could be controlled from the cockpit to give the pilot the desired stick-force variation. Although the geared-unbalancing-tab control arrangement was found to be satisfactory and indistinguishable from a conventional tail, it obviously did not have the control characteristics originally intended, because it did not fulfill the original requirements of the all-movable horizontal tail for a low value of C_{h_δ}. The tests with this control system did prove, however, that nothing is inherently wrong with the all-movable horizontal tail as a longitudinal control.

At the same time the work was being done on the all-movable horizontal tail, a related set of tests was being made to improve the longitudinal control characteristics of a P-63A-1 airplane having experimental elevators (reference 3). The British also were performing somewhat similar tests on a fighter-type airplane and their conclusions were in general agreement with those reached in the tests of the P-63A-1. As a result of these investigations, a paper discussing the need for additional requirements for satisfactory elevator control characteristics was published, reference 4.

During the course of the flight investigation of the P-63A-1, a set of highly balanced elevators $\left(C_{h_\delta} \text{ and } C_{h_\alpha} \text{ near zero}\right)$ was used in conjunction with a bobweight and was found to be unsatisfactory because of the light stick forces for abrupt stick deflections. In an effort to obtain satisfactory longitudinal control characteristics of the P-63A-1 airplane with the highly balanced elevators, a device was incorporated in the control system which consisted of a spring in series with a viscous damper attached between the control system and the airplane

structure. Better stick-force characteristics were obtained for rapid deflections, but because of the fixed spring constant the control was satisfactory only over a limited speed range.

In order to provide control-feel characteristics similar to those obtained with the spring and damper device on the P-63A-1 airplane, but for a wider speed range, the original servotab arrangement of the Curtiss XP-42 airplane was modified to include a viscous damper in the control system in order to cause the servotabs to act as geared unbalancing tabs for abrupt deflections. This arrangement would effectively provide a spring restraint on the elevator with a spring constant that would vary as the square of the airspeed. The geared unbalancing tabs were expected to supply satisfactory stick-force gradients in rapid maneuvers. The control system, however, would still act as a pure servotab for slow stick deflections. The flight-test results of this control system are presented herein.

These tests were carried out with the Curtiss XP-42 airplane having the all-movable tail because of the convenience of utilizing the existing control linkage of this airplane. This type of control system is not restricted to use with an all-movable tail, but may be applied also to a conventional tail arrangement with closely balanced elevators.

DESCRIPTION OF GEARED UNBALANCING SERVOTAB CONTROL SYSTEM

A three-view drawing of the airplane and the plan view of the horizontal tail are shown in figures 1 and 2, respectively. A diagram showing the action of the geared unbalancing servotab in three successive stages is shown in figure 3. Figure 3(a) presents a general graphical view to indicate in which way the viscous damper is incorporated in the control arrangement and also to show the position of the various parts of the system before any deflection of the control is made. Figure 3(b) shows the position of the control after the control stick has been deflected rapidly. Figure 3(c) shows the final position of the control system after a rapid deflection of the control has been made and the stick has been held in a fixed position for a period of time.

The viscous damper in the control system is the medium through which the change from a geared unbalancing tab to a servotab is possible as shown in stage B of the control motion. For rapid stick deflections, the viscous damper acts as a rigid link. Under these conditions, the control system moves the tabs and the horizontal tail in the same direction in a ratio of 1.2:1.0. If the stick is held at a certain deflection after it has been rapidly deflected, the aerodynamic force exerted on the tabs creates a moment about the elevator hinge which is transmitted through the control system, deflects the piston in the damper, and returns the

tabs to approximately zero deflection with reference to the horizontal tail. When the stick is deflected initially, the action of the damper in moving the whole horizontal tail and tabs in the same direction gives an immediate stick force that is proportional to the stick deflection, and this stick force is then gradually relieved by the ensuing servotab action. As the normal acceleration builds up, the bobweight supplies stick force. For slow movements of the stick, the damper allows the tabs to act approximately as pure servotabs. The centering springs shown in figure 3, give a simulated value of C_{h_δ} but this value decreases with airspeed to small values at high speeds. The purpose of the centering springs is to give a stick force in landing and also to give the horizontal tail a centering tendency when the airplane is on the ground. During a previous investigation (reference 2) a spring was necessary in the tab control system to take up backlash in order to eliminate an undamped oscillation caused by play in the tab control linkage. The stick forces contributed by the backlash spring shown in figure 3 are negligible.

The characteristics of the viscous damper are shown in figure 4 as the variation of stick force with stick-deflection rate with the tail locked. The damper used in this control system was quite sensitive to small changes in temperature. No temperature-compensating device was used in connection with the viscous damper in this control system, although such a device could be provided in a service installation.

Figures 5 to 7 give the linkage and force characteristics as determined in ground calibrations. Figure 5 shows the deflection of the horizontal control surfaces in relation to the stick deflection. The variation of tab angle with stick deflection was measured with the elevator in neutral; whereas, the variation of elevator angle with stick deflection was measured with the tab locked to the elevator. In both these conditions, the damping piston was free to move and the maximum deflections obtained were limited by the travel of the damping piston. Figure 6(a) presents the variation of tab angle with elevator angle with the damping piston locked in its extreme position and near neutral. The slope of these lines represents the linkage ratio of the tab acting as an unbalancing tab. Figure 6(b) shows the variation of tab and elevator angles with stick angle measured with the damper locked. The stick forces contributed by the different units of the control system are presented in figure 7.

FLIGHT TESTS AND RESULTS

The longitudinal stability in steady and turning flight and in rapid maneuvers was investigated. Some of these tests were made with

the center of gravity at 27.3 percent mean aerodynamic chord and the remainder at 30.1 percent mean aerodynamic chord.

The static-longitudinal-stability data are not presented as they were found to be similar to the characteristics found in previous tests (reference 2). The Curtiss XP-42 airplane shows a tendency to become statically unstable near the stalling speed in the power-on condition with any of the tail surfaces that have been tested.

The data obtained from turning flight with the center of gravity at 30.1 percent mean aerodynamic chord are presented in figure 8. The stick-force gradient was 10 pounds per g. This stick force is slightly heavier than the desirable stick force for this type of airplane (3 to 8 pounds per g). It may be noted that 6.5 pounds per g were obtained from the action of the bobweight and 1.3 pounds per g from the centering springs. The remaining 2.2 pounds per g are attributed to the small variation of the tab angle shown in figure 8, which was caused by a small amount of static friction in the damping cylinder. The force per g could have been reduced, however, by the use of a smaller bobweight.

In order to obtain data in rapid maneuvers, a series of pull-ups and holds were executed by the pilot at different indicated airspeeds. In the pull-up and hold maneuvers the pilot rapidly deflects the stick to a certain displacement and attempts to hold the stick fixed until a steady value of acceleration is obtained. The data obtained in these maneuvers are presented in figure 9. The stick force was proportional to the tab deflection for the initial deflection of the stick before the acceleration built up. As the tab returned to a neutral position in relation to the horizontal tail, the stick force due to the tail hinge moments approached zero and then the stick force due to normal acceleration acting on the bobweight appeared, and thus maintained the stick force that the tab had given. In some respects, the stick-force characteristics obtained differed from those intended. The runs at the lower indicated airspeeds show that, because of too rapid action of the damper, the stick force tended to fall off before the bobweight force reached its maximum value. Also, at the lower speeds the tab did not return completely to its neutral position due to static friction in the damper, and this resulted in an increased stick force. The system, however, provided the stick force upon the initial stick deflection which had been lacking with the original servotab system and the pilot felt that the stick-force characteristics in rapid maneuvers were fairly satisfactory. Furthermore, the requirement stated in reference 4 "the gradient of elevator control force per g in quick pull-ups shall never be less than in steady turning flight under the same conditions" was satisfied. The near-zero values of C_{h_α} and C_{h_δ}, which had been provided by the original servotab control, however, were retained for slow movements of the control.

The tab ratio and damper characteristics of the geared-unbalancing-servotab arrangement used are not considered the optimum. Furthermore, the arrangement tested had one undesirable feature, which is brought out in figure 3(c), wherein a comparison of horizontal-tail deflection for stages B and C is made. This comparison shows that the horizontal tail does not remain in its original deflected position but returns to 52 percent of its original deflection as the unbalancing tab returns to neutral position. This characteristic is inherent in the linkage system used in this particular control system; however, the decrease in tail deflection could be reduced by redesigning the linkages in the control system. Figure 9 shows that the effect of the decrease in tail deflection was to cause a fall-off in normal acceleration in the later stages of the pull-up and hold maneuvers and that the pilot attempted to correct for the decrease in acceleration by increasing the stick deflection.

Two time histories of the tab and elevator angles in pull-up and hold maneuvers with increased static friction in the viscous damper are presented in figure 10. In these runs, the center of gravity was at 27.3 percent mean aerodynamic chord. Figure 10 also shows that the static friction in the viscous damper prevented the tab from returning to neutral at an indicated airspeed of 150 miles per hour. As the airspeed was increased to 200 miles per hour, however, the tab returned relatively farther toward neutral. Thus, in the latter case, the tab hinge moments acting on the control linkage were larger in relation to the static friction, and the tabs could therefore return nearer to the neutral position as the airspeed was increased. These results indicate that in order to obtain the desired stick-force characteristics at all airspeeds, the static friction in the viscous damper must be kept at a low value.

Trim tabs located at the trailing edge of the servotabs as shown in figure 2 were available on the tail surface tested. These tabs were unsatisfactory as trimming devices. The trim tabs located on the geared-unbalancing servotabs initially trimmed the airplane in the wrong direction until the static friction in the damper was overcome. Therefore, during these tests, the trim tabs were always locked in a neutral position. With this type of control system, trimming could be provided by means of an adjustable bungee.

CONCLUSIONS

The Curtiss XP-42 airplane with an all-movable horizontal tail was equipped with a control system incorporating a combination of geared unbalancing tabs and servotabs in order to provide increased stick force in rapid maneuvers, which was not obtainable with the plain servotab control system. From a flight investigation of this arrangement, the following conclusions were reached:

1. A combination unbalancing tab and servotab control system of the type tested can be used to give satisfactory longitudinal control

characteristics in rapid as well as in steady maneuvers for control arrangements which possess near-zero values of tail hinge-moment variation with deflection and angle of attack.

2. The static friction in the viscous damper must be held at a low value in order to obtain the desired operation of the control system.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., September 28, 1948

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3. Johnson, Harold I.: Flight Investigation to Improve the Dynamic Longitudinal Stability and Control-Feel Characteristics of the P-63A-1 Airplane (AAF No. 42-68889) with Closely Balanced Experimental Elevators. NACA MR No. L6E20, 1946.

4. Phillips, William H.: An Investigation of Additional Requirements for Satisfactory Elevator Control Characteristics. NACA TN No. 1060, 1946.

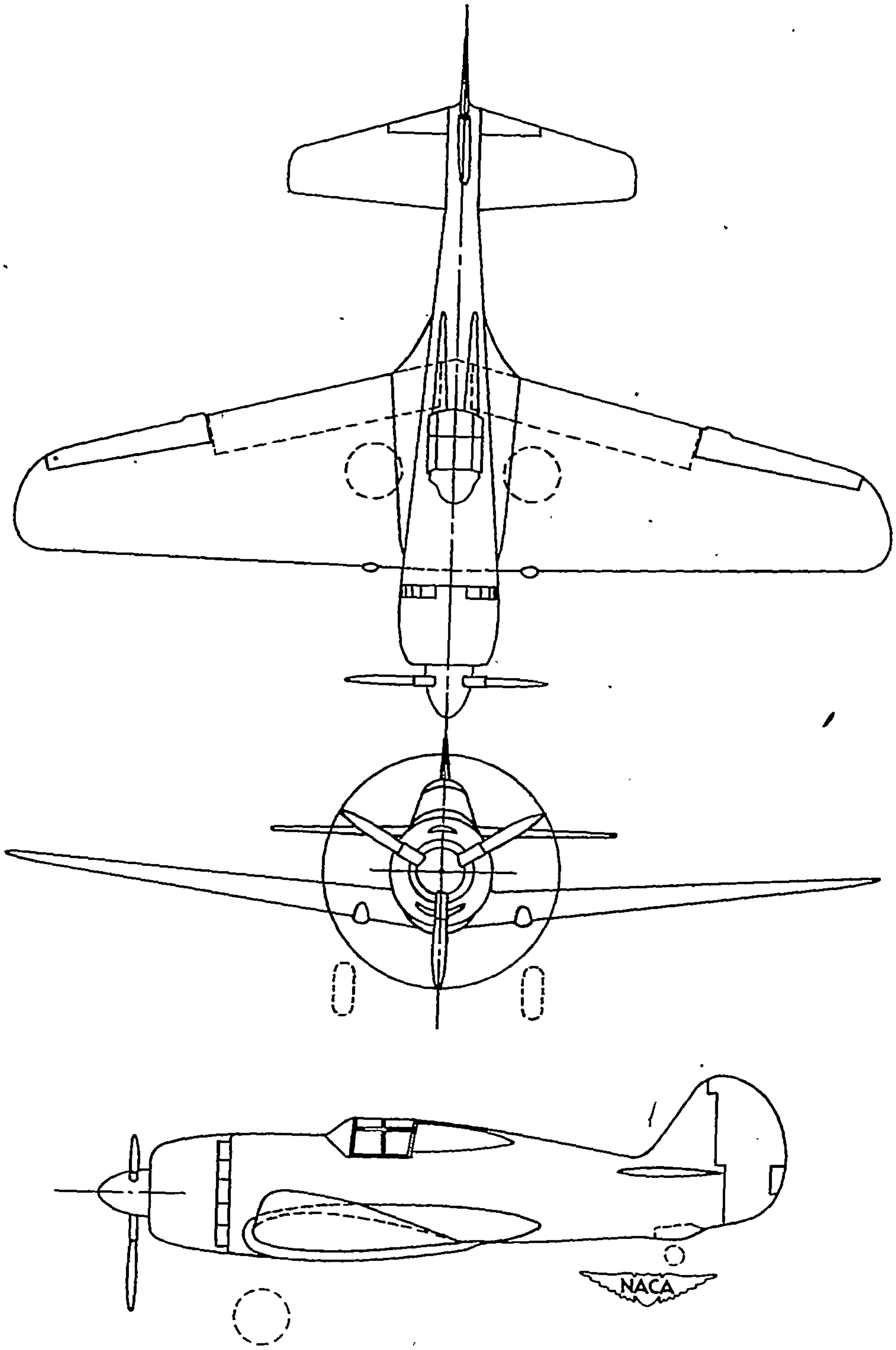


Figure 1.- Three-view drawing of Curtiss XP-42 airplane with all-movable horizontal tail.

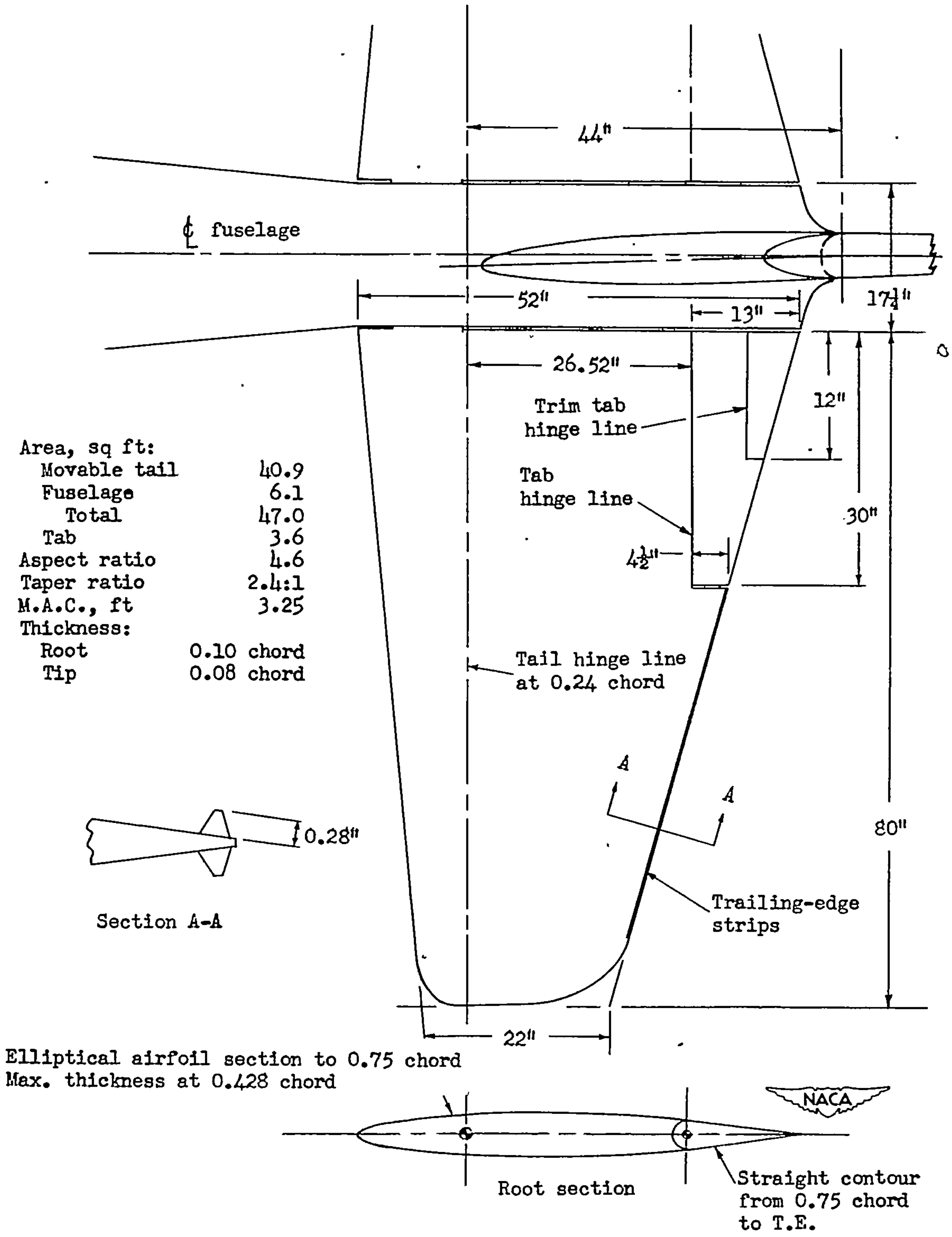
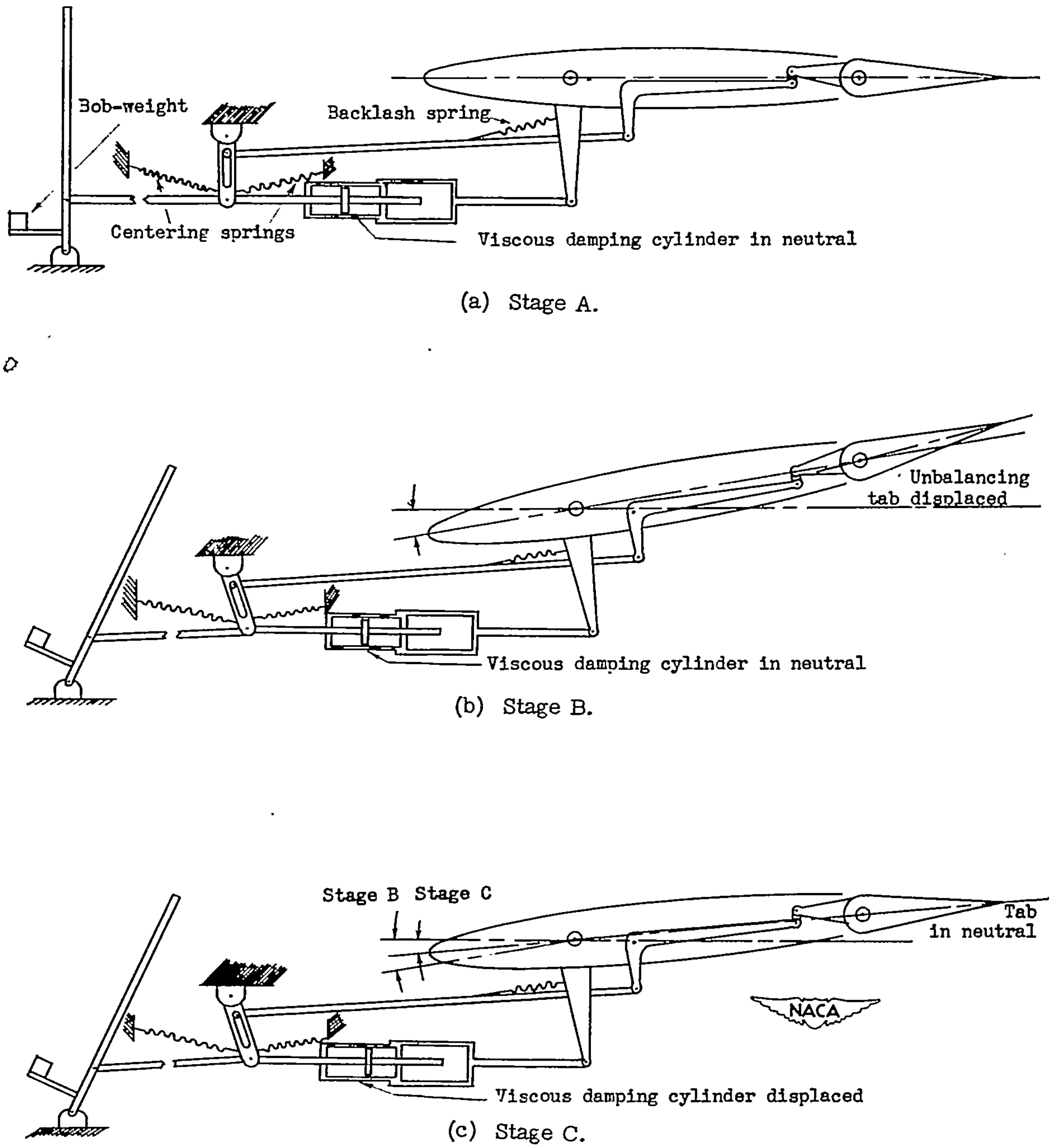


Figure 2.- Dimensions of all-movable horizontal tail for Curtiss XP-42 airplane.



(a) Stage A.

(b) Stage B.

(c) Stage C.

Figure 3.- Sketch with linkages drawn to scale of the geared unbalancing servotab control system tested on the Curtiss XP-42 airplane. This sketch gives the position of the control system at the end of three different stages.

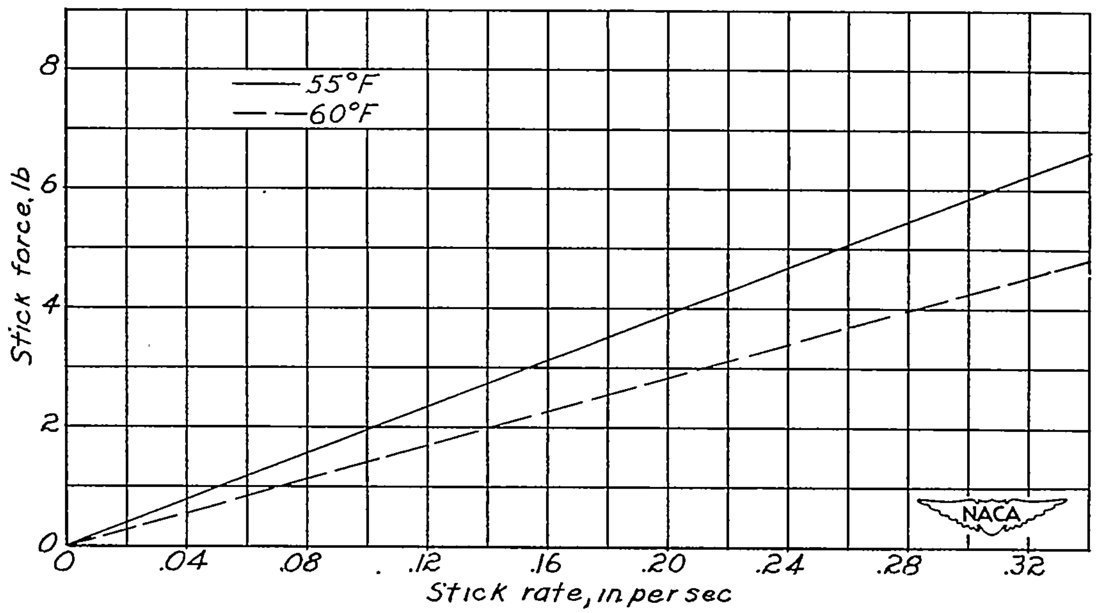


Figure 4.— Damper characteristics, used in conjunction with the geared unbalancing servotab on the all-movable horizontal tail, showing the variation of stick force with stick-deflection rate with tail locked.

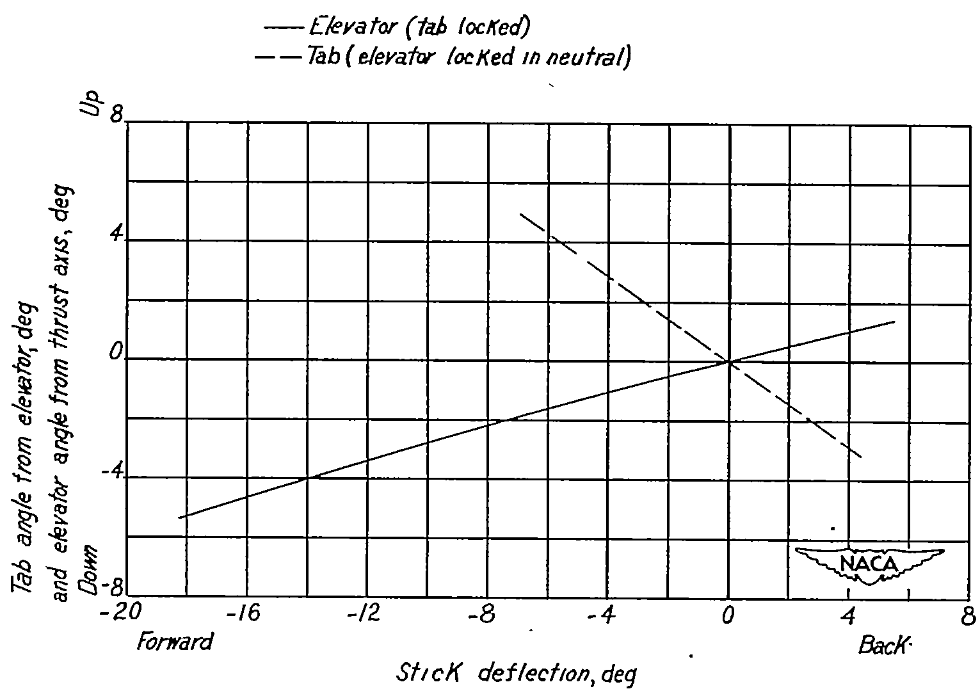
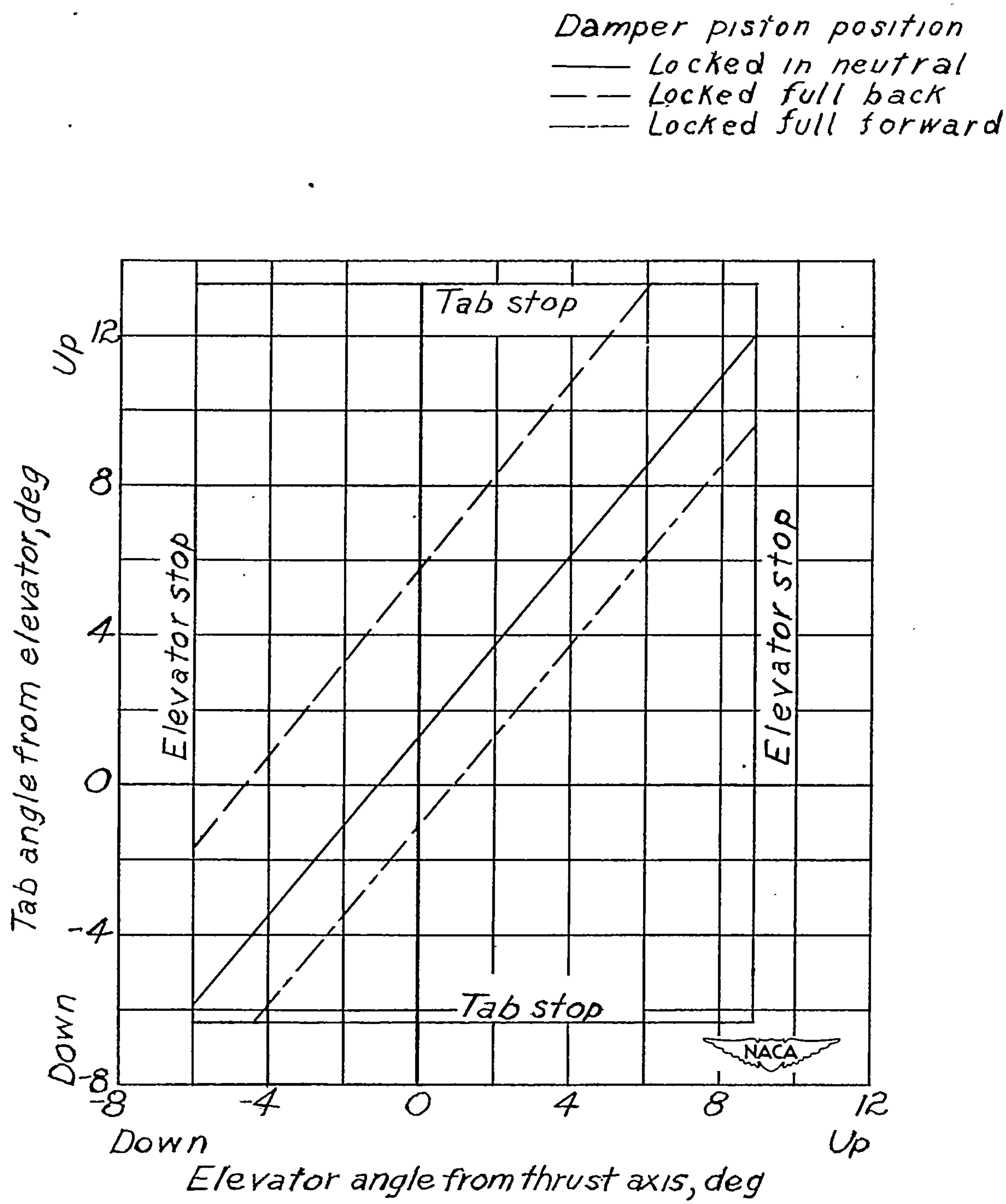
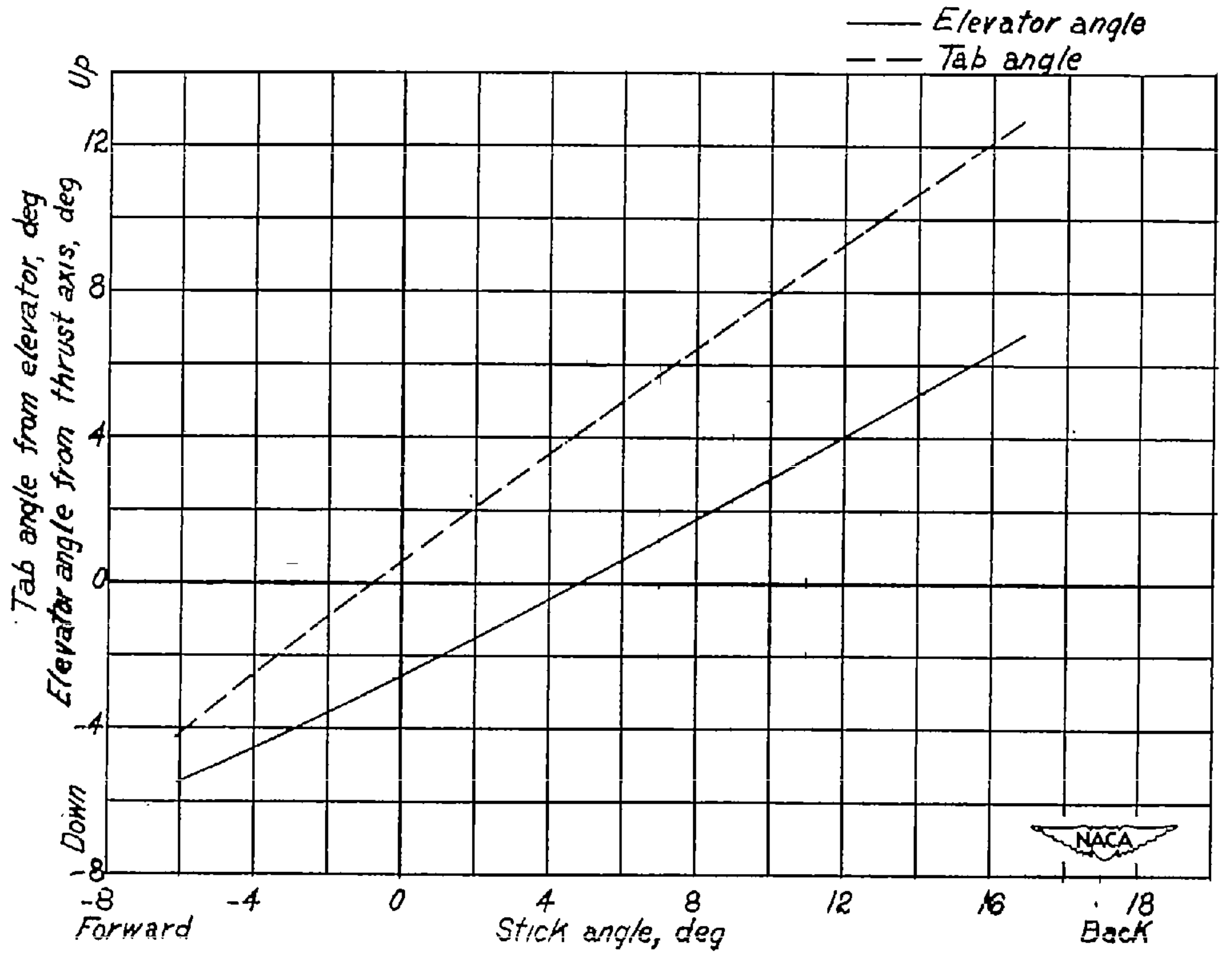


Figure 5.— Tab and elevator linkage characteristics of the geared unbalancing servotab control system tested on the all-movable horizontal tail of the Curtiss XP-42 airplane.



(a) Variation of tab angle with elevator angle.

Figure 6.- Linkage characteristics between tab and elevator control surfaces with the damper locked on the all-movable horizontal tail of Curtiss XP-42 airplane.



(b) Variation of tab angle and elevator angle with stick angle.

Figure 6.- Concluded.

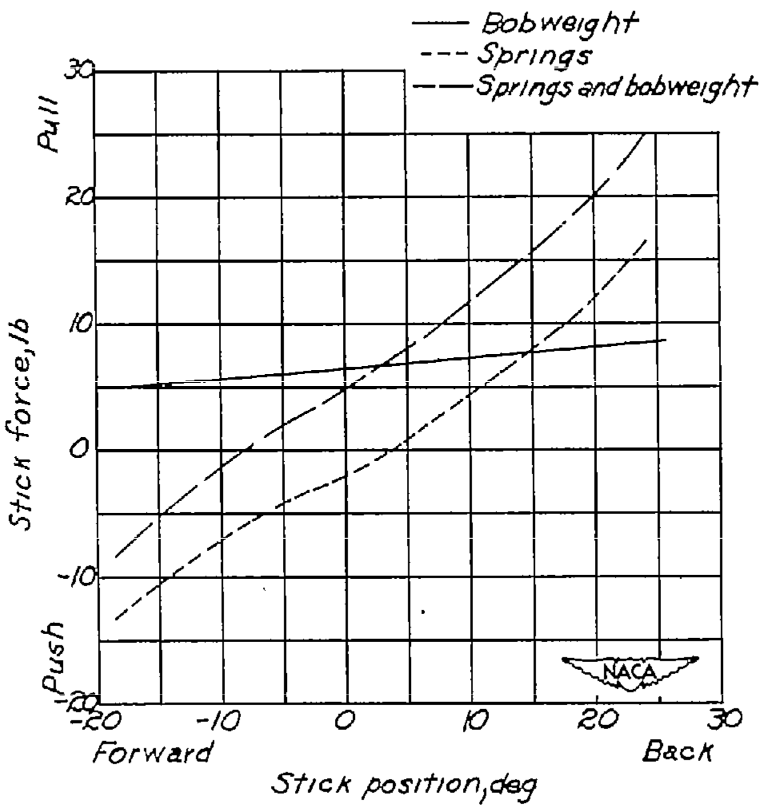


Figure 7.- Contribution of various components of the control system to variation of stick force with stick position as measured on ground for the geared unbalancing servotab control system on the all-movable horizontal tail of the Curtiss XP-42 airplane.

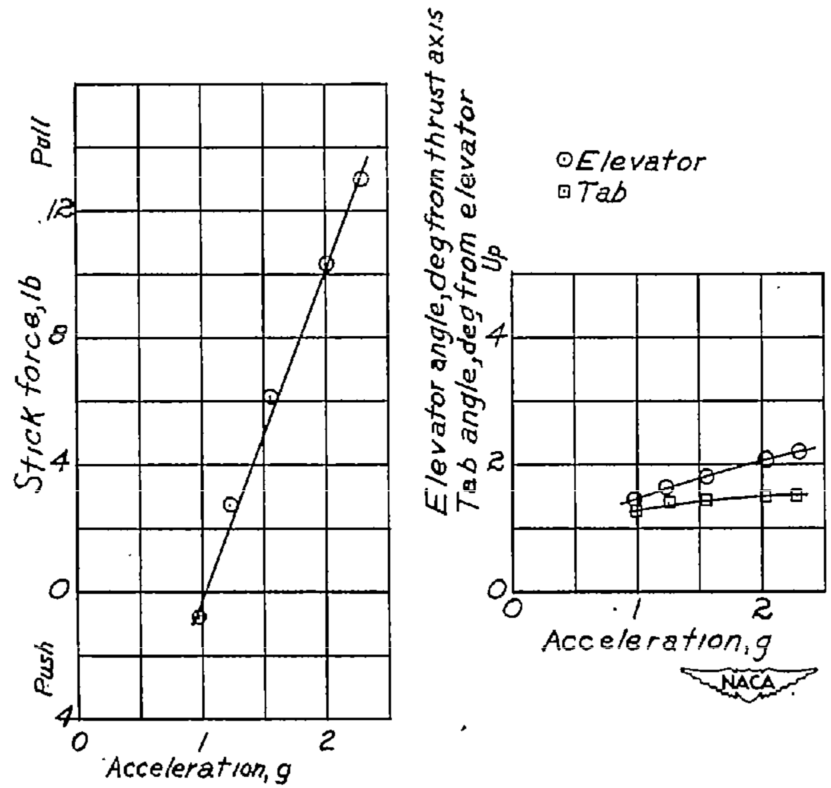


Figure 8.- Variation of stick force, elevator angle, and tab angle with acceleration obtained in steady turns at 5000 feet with geared unbalancing servotab control system on the Curtiss XP-42 airplane with an all-movable horizontal tail. Center of gravity at 30.1 percent mean aerodynamic chord.

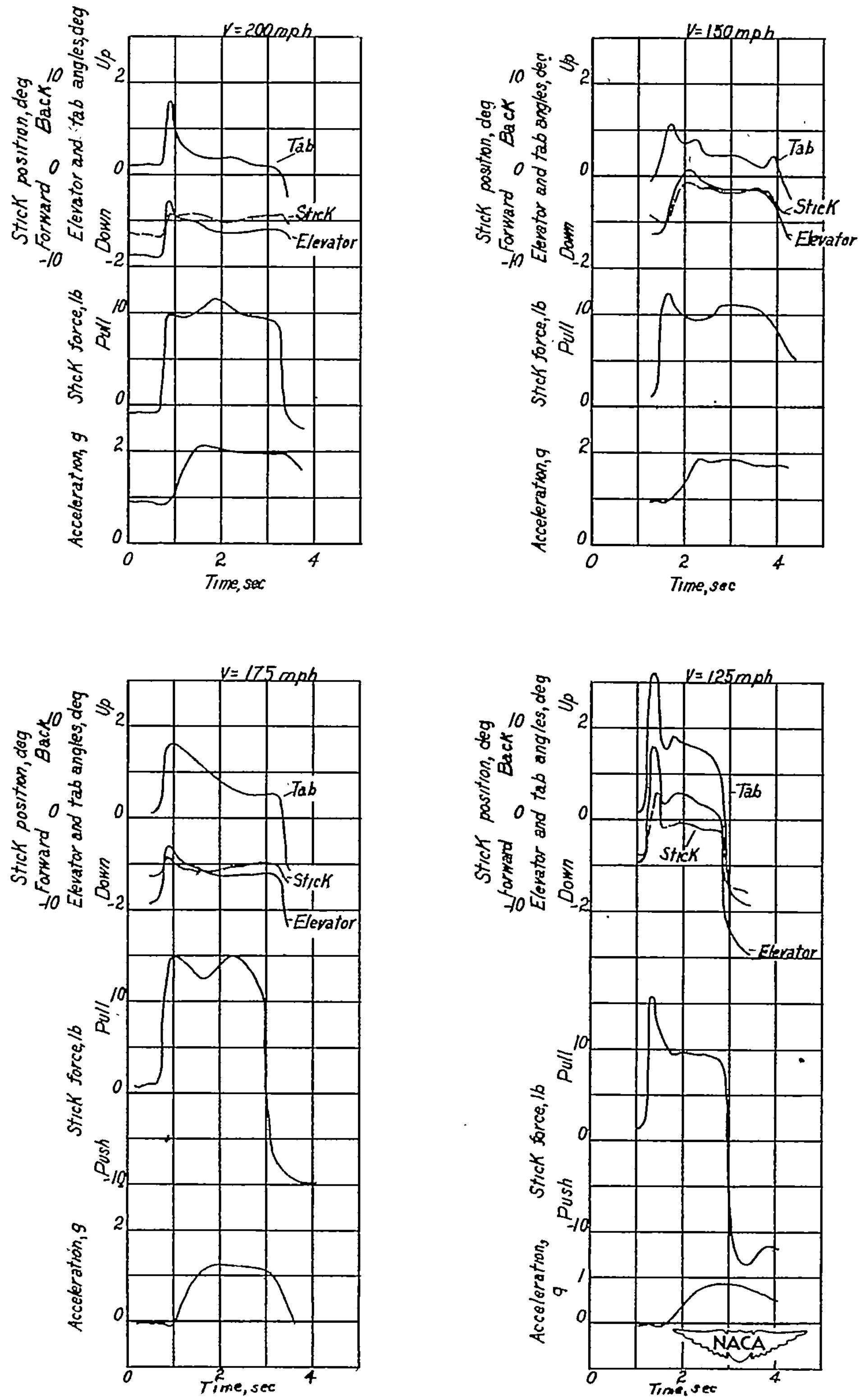


Figure 9.- Time histories of a series of pull-ups and holds with the geared unbalancing servotab control on the Curtiss XP-42 airplane having an all-movable horizontal tail. The friction was considered to be very small during these runs.

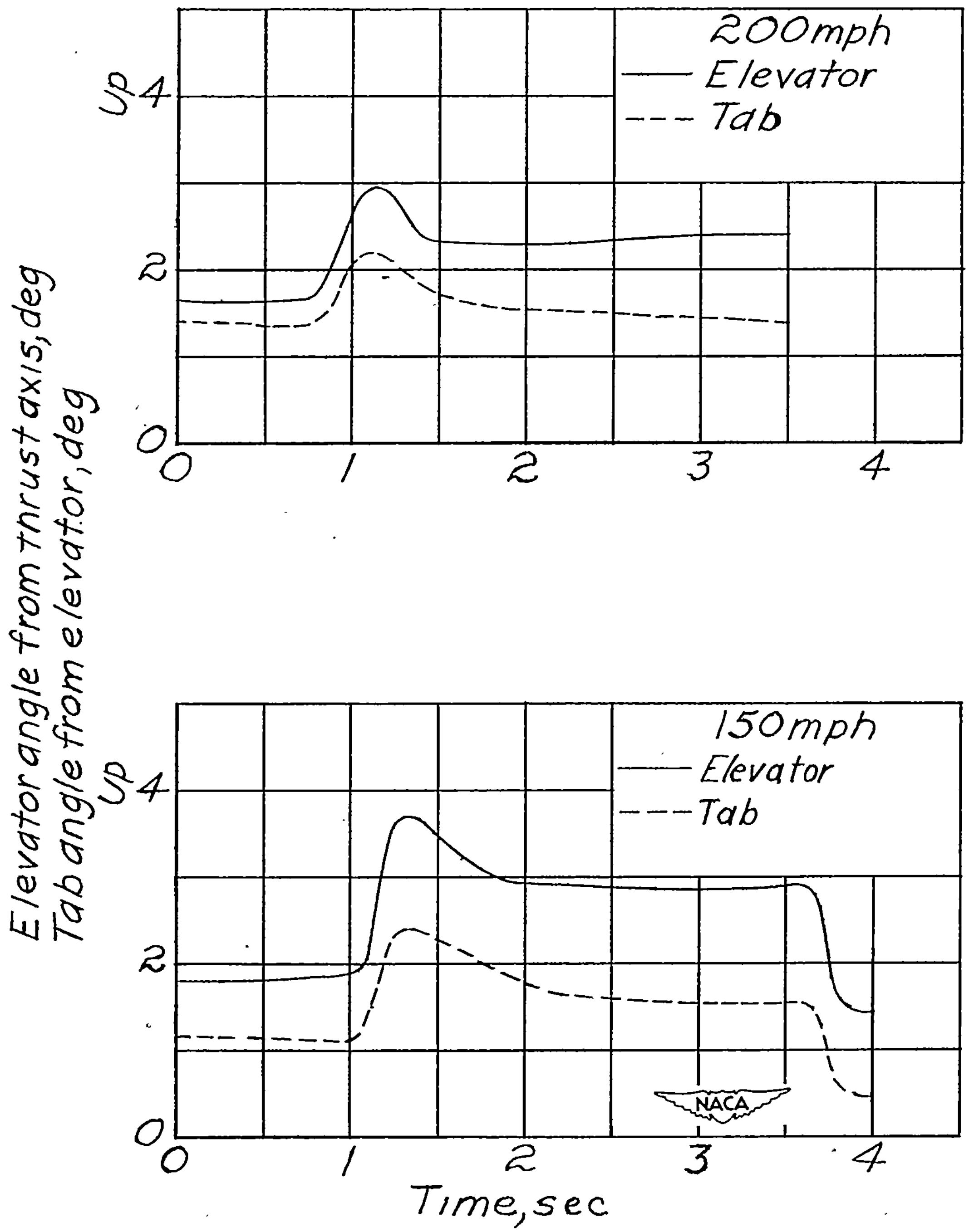


Figure 10.- Time histories of pull-ups and holds in flight at 5000 feet altitude with the geared unbalancing servotab on Curtiss XP-42 airplane having an all-movable horizontal tail. Control system had increased static friction during these runs. Center of gravity at 27.3 percent mean aerodynamic chord.